STABILITY OF CHONDRULE MELT IN THE SOLAR NEBULA. Kazuhito Ozawa[1] and Hiroko Nagahara[2], [1]Geol. Inst., Univ. Tokyo (Hongo, Tokyo 113, Japan ; ozawa@geol.s.u-tokyo.ac.jp), [2]Geol. Inst., Univ. Tokyo (Hongo, Tokyo 113, Japan ; hiroko@geol.s.u-tokyo.ac.jp).

Conditions for stability of silicate melt in the solar nebula was investigated on the basis of the phase relations determined by thermochemical considerations in a simple (Si-Mg-O-H) and the chondritic systems. Enrichment of dusts including silicates, ice, and carbonaceous components by 3.5 to 4 orders of magnitude relative to the average solar system elemental abundance is required to stabilize melts at 10^{-4} bar of total pressure and 2 to 3 orders of magnitude at 10^{-3} bar total pressure. At total pressures below 10^{-4} to 10^{-5} bar, melt is not stable. In the region where dust is enriched by more than 4 orders of magnitude, evaporation from melt is suppressed because the melt can be in equilibrium with gas. This suggests that the present size of chondrules are inherited from precursors except for porosity due to aggregation and that chemical fractionation during heating is insignificant during chondrule formation.

Origin of chondrules involves formation of silicate liquid in the solar nebula. Although the temperature regime for chondrule formation has been discussed extensively, the pressure regime has not. Chondrules and probably many CAIs were formed through complete or incomplete melting of pre-existing materials. If the melting process proceeded slowly to be in equilibrium with the solar nebula gas, the temperature-pressure conditions should have been in the stability field of liquid of the bulk composition of each chondrule or CAI. This problem has been addressed by [1] for forsterite melt and by [2] for CAI melt, but has not been fully solved yet for the chondritic system. In this paper, stability of silicate melt in the solar nebula deduced from phase diagrams constructed by thermochemical calculations will be discussed.

As a first approach, thermodynamic calculation in the system Si-Mg-O-H was made. The equilibrium was calculated by minimizing the Gibbs free energy of the system. The thermochemical data used are taken from [3] for gaseous species and from [4] for silicate melt including its nonideality and minerals. Gaseous species taken into calculation include Si, Si_2, SiO, SiO_2, SiH, SiH_4, $SiOH$, Mg, Mg_2, MgO, MgH, $MgOH$, $Mg(OH)_2$, O, O_2, H, H_2, H_2O, and OH. Condensed phases taken into consideration include MgO-SiO_2 melt, Si, SiO_2 minerals, MgO, Mg_2SiO_4, and $MgSiO_3$. Here, the Mg/Si ("dust" component) and O/H ratios are assumed to be chondritic. We varied the H/Si (or O/Mg) value, and the dust enrichment is defined as $(H/Si)/(H/Si)_{solar}$.

The lower limit for the stability of liquid in the MgO-SiO_2 system at 1600 and 1700°C is shown in Fig. 1 in the relationship between total pressure and the dust enrichment factor. The upper right of the curves is the region where either melt or melt + forsterite are stable coexisting with gas, and the lower left is the region where only gas is stable. Between these two regions, forsterite is stable with gas. The results indicate that the enrichment by 3.5 - 4 orders of magnitude is required for the formation of melt at the total pressures between 10^{-4} and 10^{-3} bar total

pressure. One of the important results of the calculation is that the melt is unstable regardless of the dust to gas ratio at calculation in a more complex system (H-C-O-Na-Mg-Al-Si-S-Ca-Fe). All solution a total pressure below ~ 10^{-5} , which is the vapor pressure of melt + forsterite.

The second approach is thermochemical phases are assumed to be ideal and thermodynamic data are taken mostly from JANAF. Elements are grouped into four nebular components, "dust", "ice", 'tar', and "gas" as suggested by [5]. Three cases are considered: one is only "dust" is enriched (f), the second is "dust" and "ice" are enriched (g), and the third is "dust", "ice", and "tar" are enriched (h). Enrichment factor of "dust", "ice", or "tar" varied from 10 to 10^5 and the total pressure ranged from 10^{-7} to 10^{-3} bar.

Fig. 2 shows results of the calculation. In the case (f), enrichment by 3.5 orders is necessary for the formation of melt at the total pressure of 10^{-4} bar, which is very close to the conclusion for the simple systems. At 10^{-3} bar of total pressure, enrichment of "dust" by 3 orders is required. In the presence of "ice", degree of enrichment required for formation of chondritic melt is a little smaller than that in the case of "dust" alone. It is about 3 orders of magnitude at 10^{-4} bar total pressure. In the additional presence of "tar", formation of liquid tends to be difficult at low pressures and enrichment by more than 5 orders of magnitude is required. Generally, presence of carbon in the system lowers the vapor pressure of oxides because of formation of carbon monoxide in gas, which resulted in expansion of the gas field and shrinkage of liquid and/or solid field. An important result of the calculation here is again that the curve becomes steep with decreasing total pressure, suggesting that formation of chondritic melt tends to be difficult at total pressures below 10^{-4} bar. We are extending this study for nonideal chondritic melt [6], because the non-ideality would expands the stability field of melt as suggested by [7].

This study suggests that in the region where dust is enriched by more than 4 orders of magnitude, evaporation from melt is suppressed because the melt can be in equilibrium with gas. The size of chondrule precursors before melting, which could be aggregates of minerals and amorphous materials originating in the solar system or extra-solar systems, had nearly the same mass as the present chondrule mass and that the chemical and isotopic fractionation was not significant during chondrule formation.

References: [1] Wood, J. A. (1963) Icarus 2, 152, [2] Yoneda, S. and Grossman, L. (1995) GCA 59, 3413, [3] JANAF (1982) Natl. Bureau Std. [4] Berman, R. G. (1983) Ph.D. thesis Univ. British Columbia, [5]Wood, J. A. and Hashimoto (1993) 57, 2377, [6] Ghiorso, M. S. and Sack, R. O. (1995) CMP 119, 197, [7] Hashimoto, A. (1991) LPS XXII, 533.

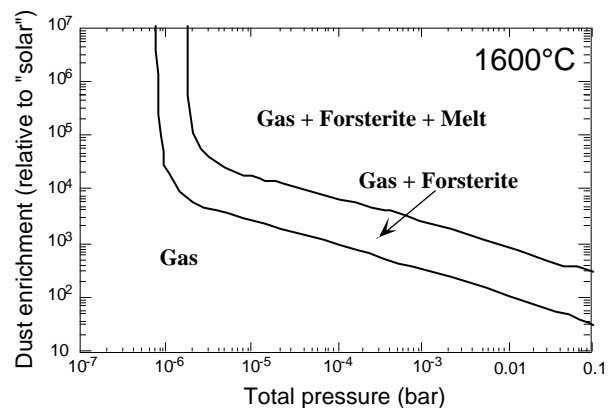STABILITY OF CHONDRULE MELT: K. Ozawa and N. Nagahara

Fig. 1-1 Stability field of silicate melt in the Si-Mg-O-H system at 1600°C.
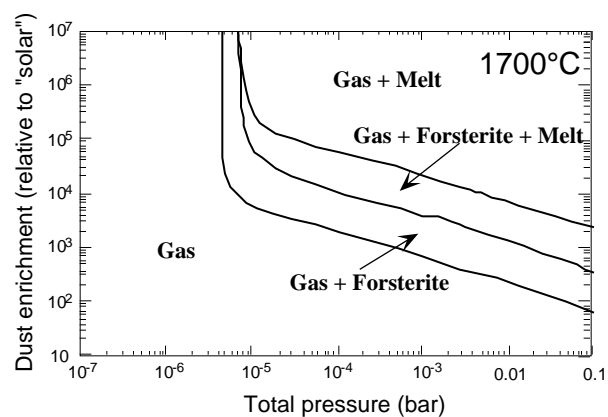
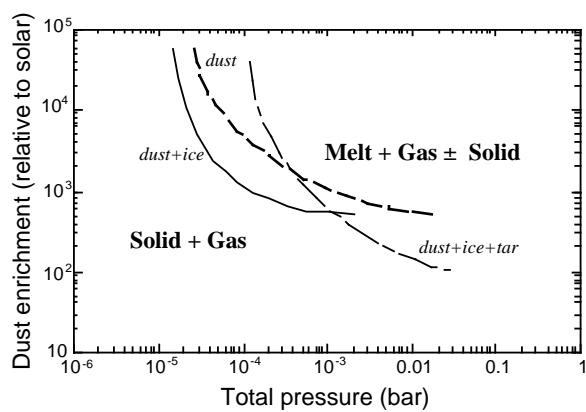Fig. 1-2 Stability field of silicate melt in the Si-Mg-O-H system at 1700°C.

Fig. 2 Stability field of silicate melt in the chondritic system at 1627°C. The broken line is for the "dust-enriched" system (case f), the solid line is for the "dust-ice-enriched" system (case g), and the dot-dash-line is for the "dust-ice-tar-enriched" system (case h). The bounaries between solid plus gas and gas alone are located near the lower left corner, but are not shown.